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FORECASTING OF TRANSIENT SURFACE SUBSIDENCE IN PRESENT UNDERGROUND MINING CONDITIONS IN POLAND

PROGNÓZA SEDÁNÍ POVRCHU PŘI SOUČASNÝCH DOBÝVACÍCH PODMÍNKÁCH V POLSKU

Abstract

The remarks on the possibilities of using geometric-integral models for forecasting of transient subsidence in the conditions of high face advance speed, as well as stoppages of face advance have been presented in this paper.

Key words: underground mining, surface subsidence, forecasting

Introduction

Present Polish underground coal mining industry has a lot of problems. Economic conditions force changes in production systems of mines. In practice, it tends toward production concentration with simultaneous increasing in longwalls length, as well as face advance speed.

Geodesic surveys led from 90's, where measurements were done day-by-day show, that in connection with face advance speed increase, as well as weekend stoppages of extraction, the distribution of transient values of deformation indices changes in comparison to continuous face advance.

One of the conditions of efficient reaction against mining damages there is possibility of working out accurate prognoses of land surface deformations. In recent years, there are lot of new proposals for description of so called dynamic troughs in Poland. One can mention here solutions proposed by J.Białek (1991), B.Drzężla (2003), J.Kwiatek (1998), P.Strzałkowski (1998). But still in Polish mining practice, the W.Budryk-S.Knothe theory has been used. So it is necessary to answer the question, how this solution meets the latest findings in this field. This paper shows, on the basis of calculation example and surveys results, the estimation of W.Budryk-S.Knothe theory accuracy for dynamic troughs, in relation to increased face advance speed as well as weekends face stoppage.

Theoretical background of w.budryk-s.knothe theory

As all geometric-integral theories, W.Budryk-S.Knothe solution assumes, that influences of elementary underground extraction area dP (fig.1) can be described by using so-called influence function :

$$f(x-s, y-t) = \exp\left\{\frac{-\pi\left[(x-s)^2+(y-t)^2\right]}{r^2}\right\} \tag{1}$$

It is a special kind of function, which integral calculated over extracted seam area is a measure of asymptotic (final) subsidence for specified point at the land surface. For chosen point A(s,t) the subsidence w(s,t) one can write as :

$$w(s,t) = -\frac{a\cdot g}{r^2}\iint_P f(x-s, y-t)\,dP \tag{2}$$

where : **g** - thickness of coal seam,

s, t - coordinates of point A in cartesian coordinate system,

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	x,y	- coordinates of elementary extraction field **dP**,
	P	- the extracted area of coal seam,
Parameters :	**a**	- coefficient of roof control. Its average value changes from 0.15 to 0.85, depending on the way of roof controlling,
	r	- main influences range.

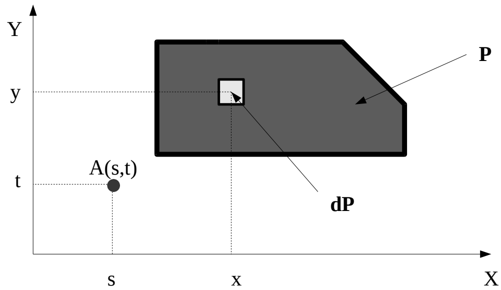

Fig.1 The sketch illustrating foundations of W.Budryk-S.Knothe theory.

The parameter **r** is connected with another parameter - **tgβ** by the equation : **tgβ=H/r**, where **H** – the depth of extraction. In the Upper Silesia Coal Basin value of **tgβ** changes from 1.5 to 3.0 in different areas. Its value depends on rock mass properties and is recognised to be constant for given area. The values of parameters **a** and **tgβ** accepted for prognoses should be determined on the basis of surveys from considered area.

The deformation indices that mainly decide on the hazard for buildings and other objects located on the ground surface are : inclination **T**, vertical curvature **K** and horizontal strain **ε**. In considered theory they are calculated as derivatives from subsidence, according to the following equations:

$$T_x = \frac{\partial w}{\partial x}, T_y = \frac{\partial w}{\partial y},$$

$$K_x = \frac{\partial^2 w}{\partial x^2}, K_y = \frac{\partial^2 w}{\partial y^2}, \quad \varepsilon_x = B \cdot \frac{\partial^2 w}{\partial x^2}, \varepsilon_y = B \cdot \frac{\partial^2 w}{\partial y^2} \tag{3}$$

where **B** is another parameter which decides on the values of horizontal displacement and strain. For prognoses, the value **B=0.4r** should be used.

The description of subsidence over time

For description of land surface deformation over time (so called “transient subsidence”), S.Knothe made an assumption, that for given point, the rate of the subsidence is proportional to difference between final value of subsidence $\mathbf{w_k}$ and its momentary (transient) value **w(t)** (in given time **t**) :

$$\frac{dw}{dt} = c \cdot \left(w_k(t) - w(t)\right) \tag{4}$$

Where:	$\mathbf{w_k(t)}$	- asymptotic value of subsidence in time “t”,
	$\mathbf{w_t(t)}$	- the value of transient subsidence in time “t”,
	c	- coefficient of subsidence rate (so called “time factor”).

S.Knothe assumed, that value of **c** is constant over time : **c(t)=const**. It is evident that due to the coal face advance, the final value of subsidence changes over time. This fact considerably complicates the solution of equation (4), which gives :

$$w(t) = \int_0^t f(\lambda \cdot v) \cdot v d\lambda - e^{-ct} \int_0^t f(\lambda \cdot v) \cdot v \cdot e^{c\lambda} d\lambda \tag{5}$$

Thus, for practical reasons it is convenient to assume, that the extracted field has a relatively small area. Accordingly, it may be assumed that the time of its extraction is close to zero. Taking this into account, the condition: $\mathbf{w_k(t)=const}$ is fulfilled. Such assumption greatly simplifies the solution of the equation (4) :

$$w(t) = w_k \cdot (1 - e^{-ct}) \tag{6}$$

For practical purposes the equation (6) may be used with employing the discrete model of face advance, where the extraction area is divided into elementary stripes which may be assumed as extracted “at once” (without delay). Taking this into account, an elementary transient subsidence is calculated for each strip. In the next step, the total subsidence is determined by summing up the values of elementary subsidence calculated for particular strips and for a given time period.

The distribution of land surface subsidence in the light of latest geodesic measurements

In recent years there is problem discussed of very quick transition of subsidence trough through the rock mass. It was pointed by A.Sroka (1999), J.Kwiatek (1998), J.Zych (2001). The analyses of geodesic measurements led in recent years show that transition of subsidence trough from the roof of extracted seam to land surface takes place in a very short time. Consistently, any longer stoppage in face advance (e.g. weekend face stoppage) is being observed on the land surface nearly without significant delay – in the beginning of the next week. Due to face stoppage, there is decrease in subsidence rate observed in diagrams presenting distribution of subsidence over time for given point (after Sroka, 1999) - fig.2.

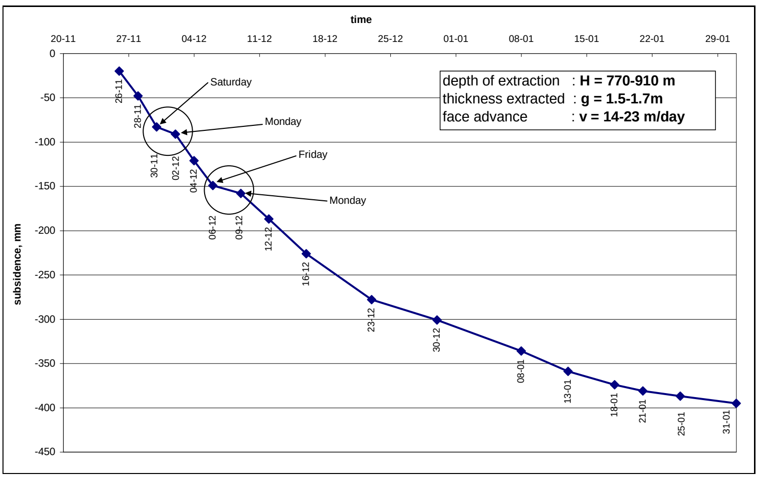

Fig.2 The example of point subsidence over time in case of extraction led with weekend face stoppage (after Sroka, 1999).

It is necessary to point here, that consequence of this observation is following statement : "values of **c** taken according to S.Knothe from the range of (0.5;7 year^{-1}) are for present mining conditions too low". So one can assume that for prognoses of transient land surface deformation higher **c** values should be taken. On the other hand it is important to answer the question : if using of high **c** values will let us properly describe the phenomenon of decreasing of surface subsidence rate due to face stoppage ?

Calculations

Trying to answer the question stated above, a practical example taken from one of the Upper Silesia Basin coal mine was considered. Some considerations have been drawn aiming to show the course of subsidence over time calculated by using W.Budryk-S.Knothe theory for different values of time factor **c**.

Practical example

In this example we examined the course of subsidence over time measured at points located directly above the extraction – fig.3. Two points chosen – No 1 and 7. Basic mining data were: depth of extraction **H=400m**, height of extracted seam **g=2.6-3.0m**, average face advance speed **v=5m/day**, maximum face advance speed **10m/day**.

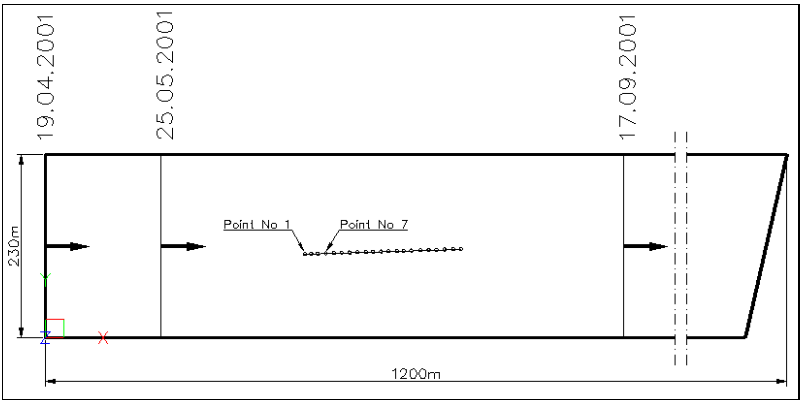

Fig.3 The location of considered observing points against coal face.

On the basis of measured distribution of subsidence over time for both points independently, the values of parameter **c** were identified by using dedicated software with least square method as the minimization criterion.

Then using obtained values of **c**, theoretical distribution of **w(t)** was compared with measured one - see fig.4. Presented results evidently showed, that despite of general good correlation between theoretical and measured course, there are no possibilities to describe the disturbance in subsidence course caused by face stoppage. Parameter **c** in Knothe solution acts here as specific "absorber" for all disturbances, especially if its value is small. Growing **c** values cause that theoretical course of subsidence over time is steeper and final values of subsidence are reached earlier.

So we should now answer another question : can we describe the disturbances caused by face stoppage by using solution proposed by S.Knothe ? In the next chapter there is an attempt made to answer the question on the background of some theoretical considerations.

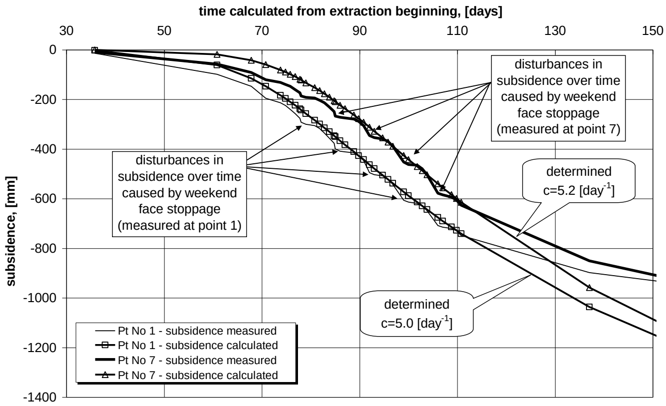

Fig.4 The comparison of the distribution of subsidence over time taken from measurements and calculated by using determined values of time factor **c.**

Theoretical considerations

For calculations purposes, the extraction field located at the depth of 500m was assumed. The length of face was 250 m, the height of 2.0 m and the speed of face advance 10 m/day. It was assumed that the extraction took place 5 day in a week : from Monday to Friday with weekend break.

Taking these assumptions into account, 5 weeks of extraction were considered. The sketch of extraction field is presented in fig. 5. By using own software for prognoses of land surface deformation on the basis of W.Budryk-S.Knothe theory (Ścigała & Strzałkowski, 2000), computer simulation of extraction was carried out. During simulation, resulting subsidence was registered for one point named „A", located at the land surface directly above the centre of extraction field. Its location is shown in fig. 5. The calculations were done for transient state of deformation with different values time factor c : 0.01, 0.02, 0.1, 0.3 [day -1], which corresponds to the range of c from 3.5 [year -1] to 100 [year -1]. Apart from that, calculation were done for $c \rightarrow \infty$, which mean that influences are „transmitted" without delay from extraction field to the land surface (it is so called „instantaneous influences"). As a result of simulation, the courses of surface subsidence over time were obtained for observed point **A** for each considered value of parameter **c**. The~~se~~ results are presented in fig.6.

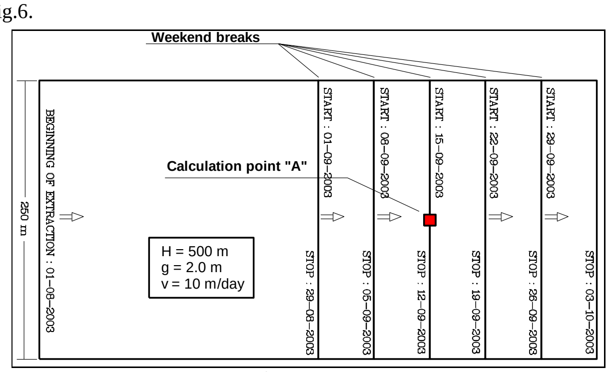

Fig.5 The scheme of considered mining extraction.

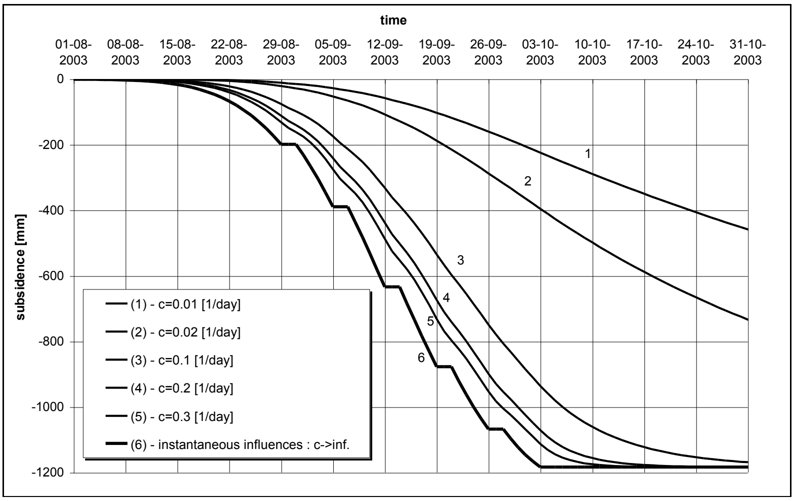

Fig.6 The time dependence of subsidence of point "**A**" located on the land surface for different values of time factor **c.**

The results of calculations allow to point some remarks concerned with quality of prognoses for transient subsidence in the conditions of high face advance speed and weekend face stoppages.

Basic conclusion is, that in calculated course of point subsidence (see fig.6), one cannot observe the disturbance in subsidence course over time due to weekend face stoppage. With used so far values of parameter **c** below 10 [year $^{-1}$] it is impossible to estimate the changes in subsidence rate that really occur on the surface after face stoppage. As it comes from the analyses of geodesic measurements presented by other authors (for example in Kanciruk, Rogowska and others, 2002), it is unequivocal, that in case of face stoppage, the speed of subsidence measured for given points considerably decreases, with a little delay in relation to this stoppage. This delay one can determine as equal to maximum several days.

Analyzing subsidence courses presented in fig.6 for higher values of **c** (e.g. c = 0.3 day $^{-1}$) it is clear, that this approach doesn't allow to describe accurately actual course of subsidence over time.

Summary

Summing up considerations presented in this paper it is necessary to point, that in the case of high speed of extraction, there are problems in forecasting of transient subsidence by using present geometric-integral models in situations, when extraction is stopped for several days (e.g. weekend breaks). In this case, land subsidence rate decreases relatively fast (see fig.2). These changes in the distribution of subsidence over time cannot be described accurately by using for example W.Budryk-S.Knothe theory. One can try to improve the quality of prediction of subsidence over time by altering „time function", for example by using rheological models with instantaneous influences. It requires however further detailed researches.

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